VLBI System for Weekly Measurement of UT1 and Polar Motion: Preliminary Results

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The DSN implementation of a system for measuring UT1 and polar motion using very long baseline interferometry (VLBI) is currently being tested. VLBI experiments are being conducted on a weekly basis on each of two intercontinental baselines. During a 17-day period in September 1979, data were obtained for seven consecutive experiments using an early version of that system. Those experiments, described here, were used to refine the estimation procedure to be used in the operational system and to provide a preliminary assessment of the performance of the system.

I. Introduction

To help meet the coming need for high-accuracy navigation at outer planet distances with rapid turnaround during encounters, the DSN will soon begin operating its own system to measure UT1 and polar motion by means of very long baseline interferometry (VLBI) (Refs. 2, 7, 8, 9). In astrometric applications, VLBI has already achieved more than an order-of-magnitude improvement in angular resolution compared to the best optical techniques (Ref. 5). Angular uncertainties at the 10-milliarc-second level are now being reported for radio source positions and additional improvements can be expected. For future spacecraft navigation the desired angular uncertainty for the orientation of the Earth is less than 0.″01 in each axis (Ref. 3). This translates to 0.7 ms in UT1 and 30 cm for both the X and Y components of polar motion. In its present configuration, the VLBI system should be able to achieve the desired accuracy with relatively short (<2 hr) passes. Previously reported experiments used from 10 hours to 24 hours of antenna time (Refs. 2 and 6).

A catalog of radio source positions is the basis for any VLBI measurement. Preliminary analyses of the effect of source position errors on the measurement of Earth orientation indicate that the source positions must be known to about 0.″01. The best sources in the JPL catalog now satisfy this requirement (Ref. 1) and continued improvement of the catalog will provide additional sources that are needed to fill gaps in certain parts of the sky.

From the known source positions the baseline vector connecting two VLBI stations can be determined in an inertial frame. If the earth-fixed coordinates of the baseline are known, Earth orientation can be determined except for a rotation about the baseline. To uniquely determine the Earth orientation it is therefore necessary to observe on two non-parallel baselines. Errors in baseline coordinates change the baseline orientation with respect to the Earth. Therefore, these coordinates must be known to an accuracy of about 0.″01 (0.3 m) in order to achieve the desired accuracies for

UT1 and polar motion. The accuracy goals for the system and a priori requirements for source positions and baseline vectors are summarized in Table 1.

The operational system, referred to as the Block I implementation, calls for weekly observing sessions of approximately 90 minutes on each of two intercontinental baselines, typically Goldstone-Madrid and Goldstone-Canberra, using 64-meter antennas. Simultaneous observations on both baselines are not possible because of visibility limitations. When the observations are not taken simultaneously, the motion of the pole and changes in UT1 between sessions introduce additional uncertainty in the estimates for these parameters. From their known rates of change, it was determined that a maximum baseline observation separation of 24 hours is consistent with the desired accuracies.

The observing schedule calls for 10 source scans (scans may repeat sources) recorded at 500 kb/s for a total of 1×10^9 bits on each of two baselines. From these data, seven parameters will be estimated: UT1, polar motion (X, Y), clock epoch offsets for two stations with respect to the third station and the two corresponding clock offset rates. In the Block I system, the data will be transmitted from each of the DSN stations to JPL over the wideband data link. It is expected that during critical events such as planetary encounters, results can be produced within 24 hours from the time of data acquisition. The operational goals for Block I are shown in Table 2.

II. Experimental Procedures

Data for the present study were recorded and processed using the developmental Block O system. The Block O procedures, summarized in Table 3, differ in certain respects from those of operational Block I. Most importantly, the number of source scans on each baseline was smaller than desired, ranging from 2 to 12, with 5 about average. In addition, the data were recorded at 4 Mb/s on video tapes, which were shipped to JPL for processing and parameter estimation.

Using the VLBI fitting software on the IBM 3032 at Caltech, Earth orientation and station clock parameters were estimated from the seven experiments summarized in Table 4. The normal operations schedule calls for a maximum separation of 24 hours between baselines, but a preliminary analysis indicates that a 48-hour separation could be tolerated. Four of the baseline pairs meet the 48-hour requirement. However, the ability to use even larger separations would be advantageous, particularly in cases where data are available for only one baseline of a scheduled pair. To test the effect of larger separations, three additional pairs of baselines were processed with separations of 7 to 15 days. The resulting reference times for the Earth orientation parameters (UT1, X-pole and Y-pole) are the means of the observation times on each pair of baselines. The pairs chosen give reference times spanning the 17-day period covered by the experiments. Each pair of baselines was used to estimate UT1-UTC, X-pole, Y-pole and the clock offsets and rates for DSS 43 (Canberra) and DSS 63 (Madrid) with respect to DSS 14 (Goldstone).

III. UT1, Polar Motion Results

Figures 1 – 3 show the results for the Earth orientation parameters. The individual experiments are shown along the time axis and are keyed by baseline. The pair of numbers next to each data point identifies the experiments from which the data were taken. For comparison, the figures show the difference between the VLBI values and the values computed by the Bureau International de l'Heure (BIH) and published monthly in Circular D. The dashed lines show the means of the VLBI-BIH values. The error bars shown do not consider the effects of errors in baseline vectors or source positions, which can introduce additional random and systematic errors in the orientation parameters. The effect of baseline time separation has been included in the errors for X-pole and Y-pole, using the rates of change of these parameters obtained from the BIH values.

The results for UT1-UTC show formal errors ranging from 0.5 ms to 4.3 ms. The large error in 68-69 is due to the small number of scans and poor data quality of experiment 68. The mean difference between the VLBI and BIH values was −0.81 ms, which is smaller than the accuracy quoted by BIH and can be attributed to a difference in the origins of the VLBI and BIH coordinate systems. With the mean difference removed, the VLBI estimates have an rms deviation from BIH of 0.91 ms. If pair 68-69 is deleted, the mean difference and rms deviation are reduced to −0.55 ms and 0.69 ms, respectively.

For the X- and Y-pole estimates, the formal errors range from 0.″008 to 0.″073. The larger errors in the baseline pairs 66-69, 67-70, and 69-70 are primarily due to the baseline separations, which are 8, 15, and 7 days, respectively. Experiment 68 again degrades the estimates for 68-69. The errors in the remaining pairs are about 0.″010, which is typical for good data on close baselines. The mean difference between the VLBI and BIH X-pole estimates is −0.″043 with an rms value of 0.″019. (With pair 68-69 deleted, the mean difference is −0.″036 with an rms of 0.″008.) The Y-pole estimates have a mean difference of −0.″005 with an rms of 0.″009.

IV. Conclusions

The rms deviations, summarized in Table 5, are a measure of the random error uncertainties in the parameter estimates. The rms values for UT1 and X-pole are larger than the desired levels given in Table 1, while the value for Y-pole is smaller. When baseline pair 68-69 is not included, the rms values for all parameters are consistent with the accuracy goals. While it is not claimed that these results constitute a validation of system performance specifications, they do indicate that the specified performance is attainable. In support of this conclusion, we note that several factors in the Block O system which contribute to the uncertainties of the estimates will be eliminated or reduced in the Block I system. Although the best available station locations and source positions were employed, they must still be regarded as preliminary because they do not completely satisfy the stated accuracy requirements. Calibrations for certain components of the VLBI delay observable will also be improved in the Block I system. The present data were processed using a fixed tropospheric delay at zenith and no instrumental delay calibration was available. In the operational system, atmospheric conditions will be monitored, including water vapor content, to determine the wet and dry components of the tropospheric delay (Ref. 4). In addition, phase calibration of instrumental delays will be performed (Ref. 10). Other sources of error are present in the models for Earth precession and nutation. These models will be improved as additional VLBI source catalog data become available. Finally, it should be possible to increase the fraction of successful source scans and to minimize the time separation between baselines through better scheduling of observations. These improvements should enable the operational Block I system to meet or exceed the specified accuracy requirements.

References

1. Purcell, G. H., et al., "Current Results and Developments in Astrometric VLBI at JPL," IAU Colloquium No. 48, Vienna, Austria, 1978.

2. Fanselow, J. L., et al., "Determination of UT1 and Polar Motion by the Deep Space Network Using Very Long Baseline Interferometry," Proceedings of IAU Symposium No. 82, Time and the Earth's Rotation, 1979, pp. 199-209.

3. Melbourne, W. G., and Curkendall, D. W., "Radiometric Direction Finding: A New Approach to Deep Space Navigation," AAS/AIAA Astrodynamics Specialist Conference, Jackson Hole, WY, 1977.

4. Resch, G. M., et al., "Atmospheric Water Vapor Calibrations: Radiometer Technique," *DSN Progress Report 42-32*, Jan.-Feb. 1976, Jet Propulsion Laboratory, Pasadena, Calif., pp. 38-49.

5. Shapiro, I. I., "Estimation of Astrometric and Geodetic Parameters from VLBI Observations," in *Methods of Experimental Physics*, M. L. Meeks, Ed. (Academic Press, New York, 1976), Vol. 12c, pp. 261-276.

6. Shapiro, I. I., et al., "Transcontinental Baselines and the Rotation of the Earth Measured by Radio Interferometry," *Science*, 186, 920-922, 1974.

7. Thomas, J. B., An Analysis of Long Baseline Interferometry, Part I, Technical Report 32-1526, Vol. VII, Jet Propulsion Laboratory, Pasadena, Calif., pp. 37-50.

8. Thomas, J. B., An Analysis of Long Baseline Interferometry, Part II, Technical Report 32-1526, Vol. VIII, Jet Propulsion Laboratory, Pasadena, Calif., pp. 29-38.

9. Thomas, J. B., An Analysis of Long Baseline Interferometry, Part III, Technical Report 32-1526, Vol. XVI, Jet Propulsion Laboratory, Pasadena, Calif., pp. 47-64.

10. Thomas, J. B., The Tone Generator and Phase Calibration in VLBI Measurements, DSN Progress Report 42-44, Jan.-Feb. 1978, Jet Propulsion Laboratory, Pasadena, Calif., pp. 63-74.

Table 1. Accuracy goals and a priori accuracy requirements

Accuracy goals	
UT1	– 0.7 msec
Polar motion	– 0.01 arc sec (0.3 m)
Accuracy requirements	
Baselines	– 0.3 m
Source positions	– 0.01 arc sec

Table 2. Operational goals

Weekly recording sessions of ~ 90 min on each of two baselines (California-Spain, California-Australia) in 24 hr

Record ~ 1×10^9 bits per baseline (10 sources)

Observe ~ 20 total sources on 2 baselines

Make measurements of UTI, polar motion (X, Y), clock epoch offset, clock rate offset

Eventual 24-hr turnaround

Table 3. Experimental procedures

Observe on two baselines
- 30 – 90 min (2 – 12 sources) each baseline
- S- and X-band observations
- 28.2 MHz synthesized bandwidth

Record 4 Mbs data on video tape recorders
Correlate and estimate at JPL

Table 4. VLBI experiments

Experiment no.	Date, 1979	Baseline[a]	Sources
7966	10 Sept	14-63	4
7967	10 Sept	14-43	5
7968	17 Sept	14-63	2 (X-band only)
7969	18 Sept	14-43	5
7970	25 Sept	14-63	7
7971	25 Sept	14-43	12
7972	27 Sept	14-43	5

[a]Station codes: 14, Goldstone; 43, Canberra; 63, Madrid.

Table 5. Summary of UT1 and polar motion results

	VLBI – BIH	VLBI rms
UT1 – UTC	–0.81 ms	0.91 ms
X-pole	–0.043 arc sec	0.019 arc sec
Y-pole	–0.005 arc sec	0.009 arc sec

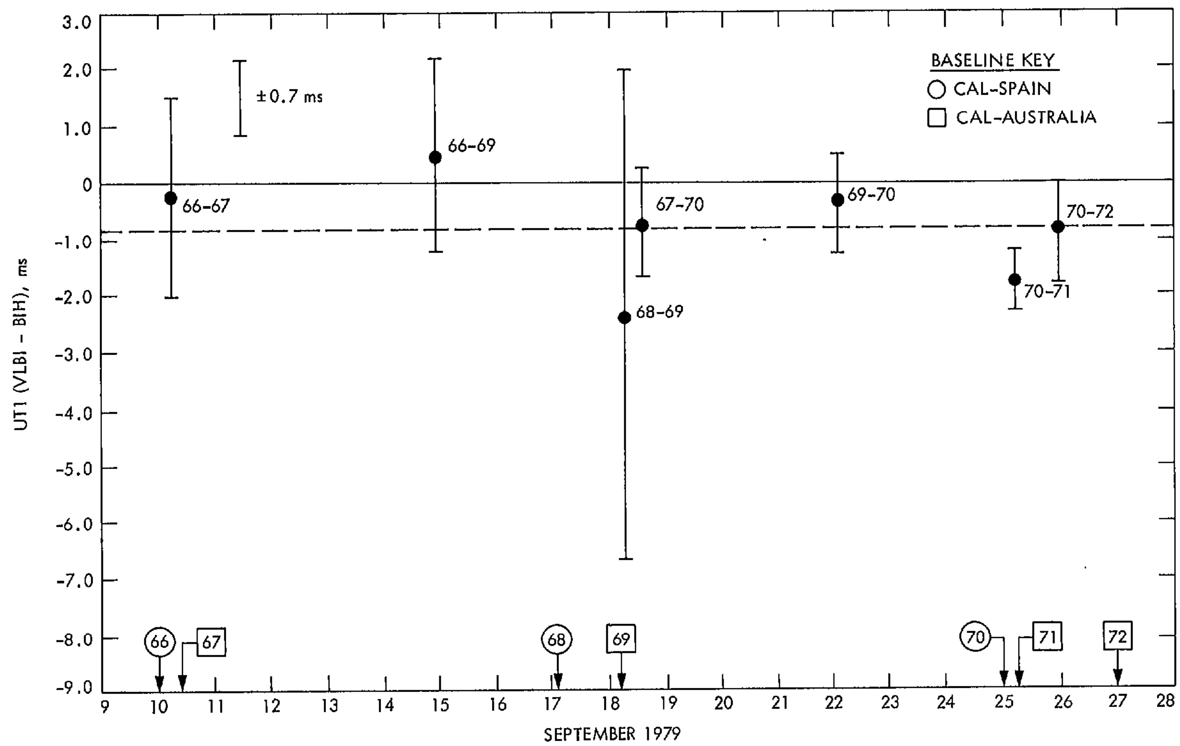

Fig. 1. UT1

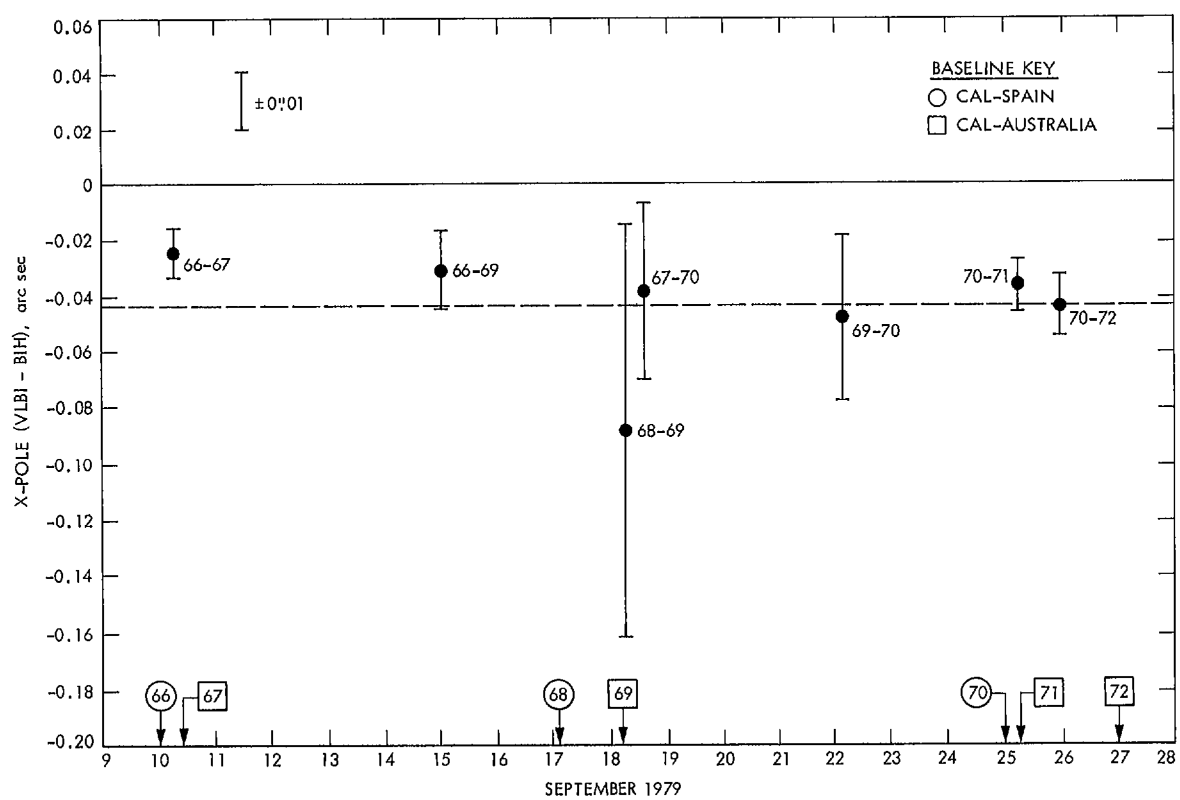

Fig. 2. Polar motion (X-pole)

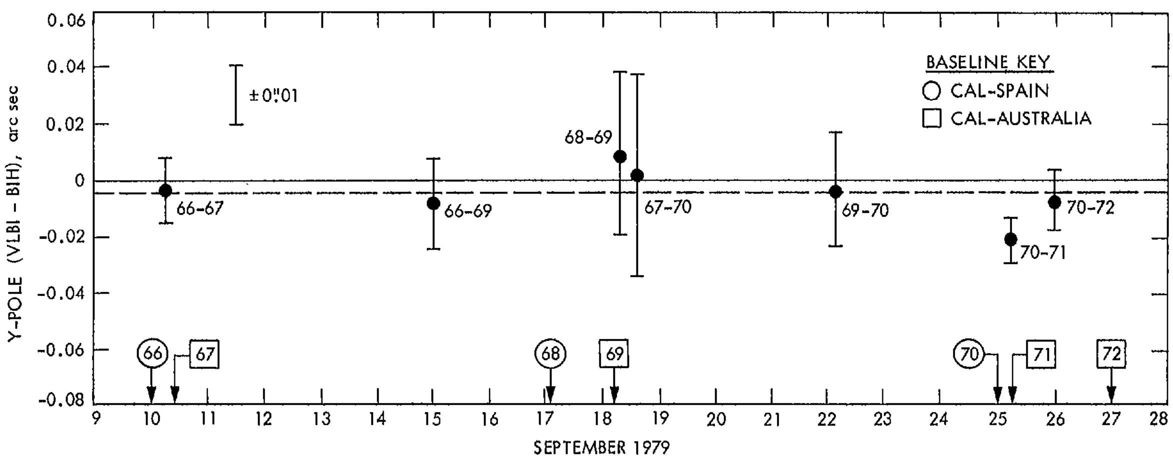

Fig. 3. Polar motion (Y-pole)